SVC Light® for railway load balancing

The growth of train traffic and the increased speed of trains in France is resulting in deterioration of power quality in the electric power systems feeding the railways. This is the case in particular for voltage unbalance, produced by single-phase connection of railway substations to the national three-phase power transmission and sub-transmission grid.

Evron is a substation in the French rail system between Paris and Rennes in Western France, fed from the RTE national power grid. An SVC Light®, supplied by ABB, is operated by SNCF (the French railway company) for dynamic balancing of asymmetry between phases caused by the mode of traction feeding, take-off of power between two phases in the three-phase grid. The project was executed in collaboration between ABB, RFF (the owner of the railway infrastructure) and SNCF.

An analysis of the situation revealed that there was a need for a technical solution which could balance in an efficient and cost-effective way the heavy and strongly time-varying single-phase loads, as well as provide active filtering of harmonics from the trains. SVC Light fulfils these demands. A system such as SVC Light, having the ability to generate voltages with any amplitude and phase angle, can meet the conditions necessary for a load balancing system. The voltage can be controlled in amplitude, phase and frequency, with full independence between the three entities. In addition, with high-frequency pulse width modulation (PWM), SVC Light is also capable of synthesizing negative sequence voltages, a requirement for load balancing.

The SVC Light also performs the task of active filtering of harmonics generated by thyristor and diode locomotives up to and including the 9th harmonic without the need for passive filters. Active filtering is made possible by the high dynamic response inherent in SVC Light.

By installing the SVC Light, the conditions set out in the National Grid Code concerning power quality at the point of connection to the grid of the traction feeder were fulfilled, i.e. requirements on limits for voltage fluctuations, phase unbalance and harmonic distortion were met. An alternative to the SVC Light would have been to build a new overhead line, to increase the fault level of the feeding grid. In feasibility studies performed before the project, it was demonstrated that the SVC Light approach was considerably less costly as well as less time-consuming than building new lines[1)]. Not having to build new lines was also very attractive from the environmental and concessional points of view.

The ability of the SVC Light to act as an active filter was a further attractive feature of this technical solution, since it eliminated the need for comprehensive installations of passive shunt harmonic filters. Also mentioned as beneficial with the SVC Light solution is its compact design, occupying only a small space in the substation.

In the VSC, there are four IGBT valves and two diode valves in each phase leg, Fig. 2. The valves are built up of stacked devices with interposed coolers and with external pressure applied to each stack. Water cooling is utilized for the valves, giving a compact converter design and high current handling capacity.

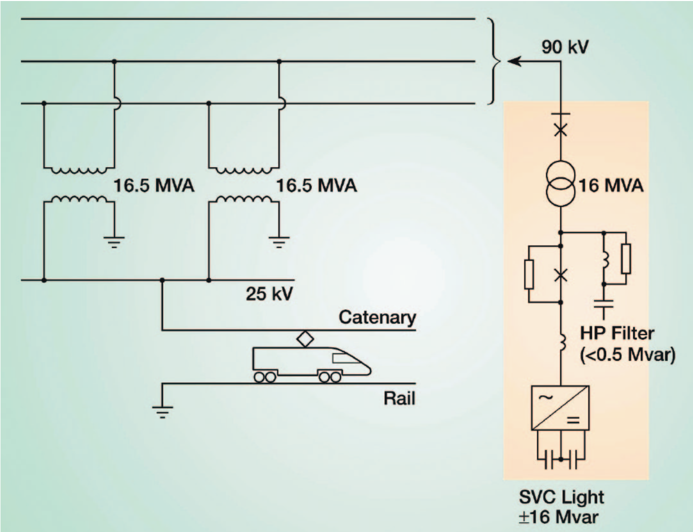

Fig. 1: Single-line diagram of the Evron 90 kV Load Balancer.

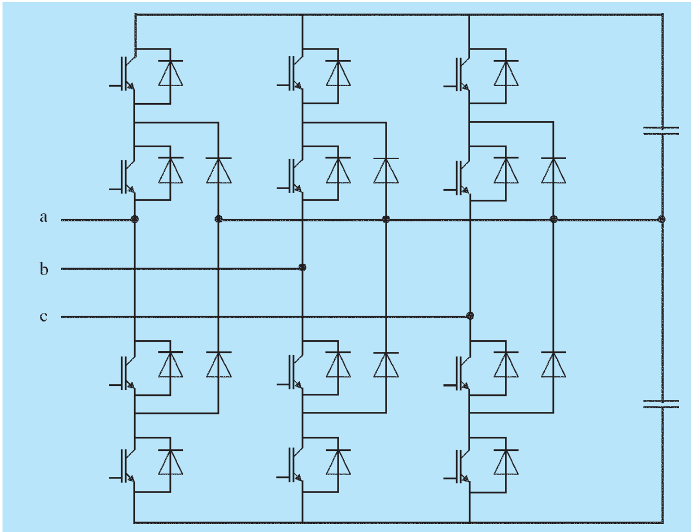

Fig. 2: 3-level VSC configuration.

Load balancing

The load balancer is rated at 90 kV, ± 16 Mvar. Its configuration is shown in Fig. 1. It is rated to accommodate a single-phase active load P as follows:

$P \leq 17$ MW (10 min average)
$P_{max} = 27$ MW / 1 sec.
P.F. = 0.84

The task of the SVC Light is to confine the grid unbalance at the 90 kV point of common coupling as follows:

≤ 1% for $S_{SC} \geq 600$ MVA (normal network conditions);
≤ 1.5% for 300 MVA ≤ $S_{SC} \leq 600$ MVA (abnormal (N-1) network conditions).

SVC Light®

SVC Light is ABB's trade name for STATCOM, based on a three-level voltage source converter (VSC) design, utilizing IGBT (insulated gate bipolar transistor) as switching element and a control concept based on PWM (pulse width modulation). The main building blocks of the SVC Light are the VSC, rated at 16 MVA, a 16 MVA, 90 kV step-down transformer, and an air-core phase reactor for coupling the VSC to the 90 kV sub-transmission grid via the step-down transformer. There is also a very small ripple filter, for filtering high-order harmonics generated by the VSC.

[1)] The SVC Light solution was estimated to be pricewise very attractive in comparison with having to build 10 km or more of 90 kV overhead line. [1]: *Cigré B4-103, 2006*

One side of the VSC is connected to a capacitor bank, which acts as a DC voltage source. The converter produces a variable AC voltage at its output by connecting the positive pole, the neutral, or the negative pole of the capacitor bank directly to any of the converter outputs. By use of PWM, an AC voltage of nearly sinusoidal shape is produced without any significant need for harmonic filtering. This contributes to the compactness of the design, as well as robustness from a harmonic interaction point of view.

Unbalance improvement

Measurements performed since the installation of the SVC Light have shown a distinct improvement in voltage unbalance, Fig. 3 [1]. With the SVC Light in operation, the voltage unbalance does not exceed 1%.

Active filtering

The active harmonic current suppression is based on generating harmonic currents in the SVC Light in phase opposition to the currents from the load. This is done by modulating the converter terminal fundamental voltages by higher frequencies. Filtering performance and the order of harmonics that can be handled are strongly related to the converter switching frequency. In the Evron case, the active filtering is effective up to and including the 9th harmonic.

In Fig. 4, the effectiveness of load balancing in conjunction with active filtering is demonstrated. In the upper graph, the total load current in all three phases at the point of common coupling is displayed, ridden with low order harmonics. The current in one phase is zero. The lower graph shows the balanced and filtered currents in the three phases. Please note the three symmetrical phase currents offset at 120 degrees. What remains of distortion in the waveforms is some ripple emanating from the load and from the SVC Light.

SVC Light benefits

The benefits of installing SVC Light can be summarised as follows:

Technical

Voltage unbalance at Evron 90 kV PCC (10 minutes, @ min S_{SC})	
Without SVC Light	Max 7%
With SVC Light	Max 1.5%: Grid Code fulfilled!

Investment cost

SVC Light less costly than building a new 90 kV OH line.

Environmental impact

Less than for building a new 90 kV OH line.

Main technical data, SVC Light

System voltage	90 kV
Rated power	16 Mvar inductive to 16 Mvar capacitive
VSC	16 MVA three-level, neutral-point clamped converter, IGBT based, pulse width modulated (PWM).
Control system	Dynamic negative sequence control of the fundamental current, dynamic positive and negative sequence control of harmonic currents, by means of a closed-loop, high-speed digital controller.
Active filtering	Up to and including the 9th harmonic

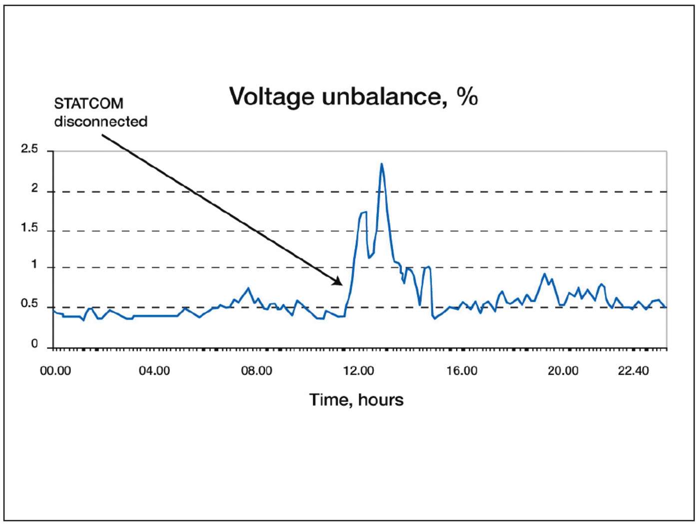

Fig. 3: Measurement of voltage unbalance (10 min values).

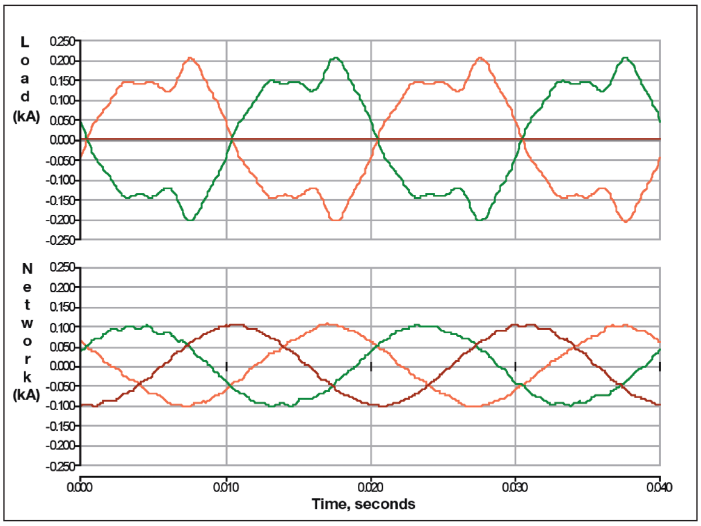

Fig. 4: Load balancing and active filtering.

Principle of load balancing

The load balancer transfers active power between the phases in order to create a balanced load seen from the supergrid. A short graphic illustration is shown to provide some clarity to the concept.

The load current can be expressed by phase vectors. If the load is connected between two phases (B & C) only, two phase vectors can express the traction current, one representing the positive phase sequence and the second one representing the negative phase sequence (Fig. 5). The sum of the two vectors is the resulting current (the current of phase A is zero and the currents in phase B and C are of equal magnitude but phase-opposed). Note that the vector amplitudes are not truly representative.

To compensate the negative-phase sequence and thus balance the current to be generated by the power systems, the load balancer generates a negative phase sequence current as shown in Fig. 6.

The load balancer (I_{LB}) is a pure negative phase sequence current. Please note that the current generated by the load balancer (I_{LB} in Fig. 6) exactly balances the negative phase sequence current from the load (I_{-LOAD} in Fig. 5).

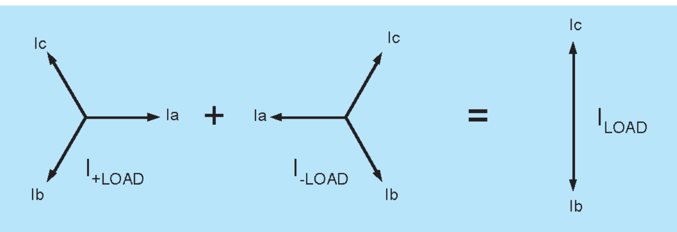

Fig. 5: Phase sequence components of the load current.

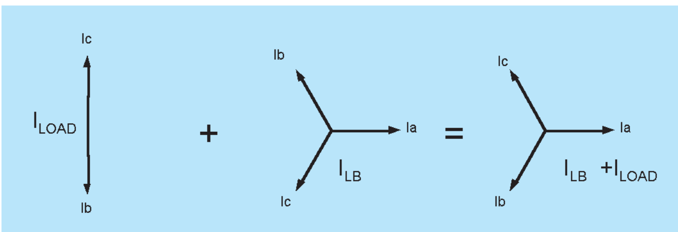

Fig. 6: Balancing the load current.

For more information please contact:

ABB AB
FACTS
SE-721 64 Västerås,
SWEDEN
Phone: +46 (0)21 32 50 00
Fax: +46 (0)21 32 48 10

www.abb.com/FACTS

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